NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1380

THE 1350° F STRESS-RUPTURE PROPERTIES OF TWO WROUGHT ALLOYS AND THREE CAST ALLOYS

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SUMMARY

The rupture-test characteristics at 1350° F of two wrought alloys, NR-82 (6059 modified-low carbon) and NR-84 (N-155 modified-low carbon) and the three precision-cast alloys, NR-71 (X-40), NR-87 (Co-Cr-Ni base-9Mo) and NR-90 (Co-Cr-Ni base-5Mo, 5W) have been determined. The two wrought alloys were tested in the solution-treated and aged condition and the cast alloys were aged before testing. The principal results obtained were:

Alloy	Rupture strength at 1350° F (psi)	
	100 hr	1000 hr
Wrought NR-82	32,500	24,000
Wrought NR-84	32,500	24,000
Cast NR-71	45,000	33,000
Cast NR-87	44,500	36,000
Cast NR-90	41,000	34,000

These properties compare favorably with those of the strongest similar alloys previously investigated. However, compared with a 60Cr-25Fe-15Mo alloy, the three cobalt-chromium-nickel cast alloys are inferior.

A correlation of NACA and OSRD (Project NRC-8) data is presented, showing the variation of rupture strengths with temperature in the range of 1350° to 2000° F for the alloys.

INTRODUCTION

A program of research, which has as its aim the development of better alloys for use at the elevated temperatures encountered in the present-day-aircraft power plants, is in progress under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics at the University of Michigan. As part of this investigation, the rupture-test characteristics of two new wrought alloys and three new cast alloys were studied at 1350° F. This work was begun because the 1500° and 1600° F properties, determined in the OSRD research program (references 1 and 2) showed these to be promising alloys.

TEST MATERIALS

Five alloys, two in the wrought form and three as castings, were submitted as test specimens in the heat-treated condition by the National Research Council (Project NRC-8). Only material sufficient for the 1350° F rupture tests was supplied.

Chemical analyses of the five alloys are given in table I. The two wrought alloys, NR-82 and NR-84, are modifications of two alloys previously investigated. NR-82 is Alloy 6059 in which the carbon was lowered from 0.46 to 0.17 percent and one-half of the 6 percent molybdenum replaced by 2 percent tungsten and 1 percent columbium. NR-84 is a modification of alloy N-155 in which the carbon is 0.14 percent instead of 0.35 percent; chromium, nickel, and cobalt each raised from 20 to 23-24 percent; and the molybdenum-tungsten-columbium ratio changed from 3:2:1 to 4:1:1. The cast alloys, NR-71 (X-40), NR-87, and NR-90, are cobalt-chromium-nickel base alloys with varying amounts of molybdenum and tungsten.

Manufacturing procedure and heat treatment of the five alloys are as follows:

Alloys NR-82 and NR-84 were produced by the Union Carbide and Carbon Corporation. They were melted as 100-pound basic induction heats, hot-forged from 2100° to 1400° F from 3-inch-square ingots to 1-inch-square bars. Both alloys were solution-treated 1 hour at 2200° F, water-quenched, and aged 50 hours at 1350° F. Test specimens 0.250 inch in diameter were machined from the 1-inch bars.

Alloys NR-71, NR-87, and NR-90 were produced by the Haynes-Stellite Company. They were melted as $2\frac{1}{2}$-pound heats in an indirect arc-rocking furnace and precision-cast as 0.250-inch-diameter test specimens. The specimens were aged 50 hours at 1350° F before testing.

PROCEDURE

Stress-rupture tests at 1350° F were run to at least 1000 hours to determine the rupture strengths for the five alloys. The longest-time rupture-test specimen of each alloy was examined metallographically and its hardness determined.

The rupture tests were conducted as follows: The stress was applied to the specimen by weights acting through a simple beam and system of knife edges. The specimens were held at test temperature for approximately 24 hours before application of the load to allow for temperature-distribution adjustments. Time-elongation data were obtained for the tests by measuring the drop of the loading beam during the test.

The longest-time rupture-test specimen of each material was sectioned longitudinally adjacent to the fracture. Photomicrographs at a 100-diameter magnification were taken of the fractured portion of the specimen and at a 1000-diameter magnification of the interior structure of the specimen near the fracture.

Vickers hardness tests were made on the metallographic specimens.

RESULTS

The 1350° F rupture-test results for the five alloys studied are given in table II. These data are plotted in figure 1 on logarithmic coordinates of stress against time for rupture. The rupture strengths and the estimated rupture-test ductilities at 100, 500, and 1000 hours are given in table III.

The two solution-treated and aged wrought alloys, NR-82 (6059 modified-low carbon) and NR-84 (N-155 modified-low carbon), gave identical rupture strengths of 32,500 psi for rupture in 100 hours and 24,000 psi for 1000-hour rupture. Alloy NR-82, however, had an estimated elongation to rupture in 1000 hours of 9 percent, compared with 30 percent for alloy NR-84.

The three cast alloys had strengths ranging from 41,000 to 45,000 psi for rupture in 100 hours and 33,000 to 36,000 psi for rupture in 1000 hours. At 100 hours, alloy NR-71 (X-40) had the highest strength, but for longer time periods alloy NR-87 was the strongest. Comparative estimated elongations to rupture in 1000 hours were 40, 18, and 8 percent for alloys NR-71 (X-40), NR-87 (Co-Cr-Ni base-9Mo), and NR-90 (Co-Cr-Ni base-5Mo, 5W), respectively.

Photomicrographs of the longest-time rupture-test specimen of each alloy are shown in figures 2 and 3. Inasmuch as only sufficient material for the rupture tests was supplied, no metallographic samples of the original materials could be prepared. Representative original microstructures of some of these alloys can be found in references 1 and 2.

Vickers hardness values determined on the metallographic specimens are given under the corresponding photomicrographs in figures 2 and 3.

DISCUSSION OF RESULTS

The five alloys investigated had relatively high rupture strengths at 1350° F on the basis of a comparison with five other alloys previously investigated (reference 3). (See table III.) These five alloys which have shown excellent properties are: N-155 and cast 6059, the standard alloys of which the two wrought alloys are modifications; low-carbon N-155; cast 422-19; and cast 60Cr-25Fe-15Mo alloy.

Wrought alloy NR-84 (N-155 modified-low carbon) had rupture strengths at 1350° F approximately 4000 psi higher than the standard wrought alloy N-155 when hot-worked, the condition which gave the highest strength for N-155 at 1350° F. It was also somewhat stronger than wrought alloy low-carbon N-155 with a heat treatment similar to that of NR-84. It therefore seems, from a strength standpoint, that the composition modification of NR-84 was beneficial. Although table III shows that the strength of alloy NR-84 was much lower than the strongest condition (hammer forged) reported for low-carbon N-155, this particular heat was worked down to 1350° F and had excessively high strengths due to this hot-cold work.

No comparison on a similar treatment basis is possible for wrought alloy NR-82 (6059 modified-low carbon), because the unmodified 6059 alloy has not been tested in the wrought condition. It does have lower strength than cast standard 6059. However, castings usually have higher rupture strengths at 1350° F than wrought materials.

The cast alloys had similar rupture strengths. Variations in rupture times from those predicted by the rupture curve, which were possibly due to varying crystal orientation between specimens, make it impossible to attribute the slight strength differences observed to chemical composition.

The strengths of these three alloys are of the same order of magnitude as that of the best cast cobalt-chromium-nickel base alloy (422-19) previously tested at 1350° F. They have much lower strength, however, than cast 60Cr-25Fe-15Mo, which is one of the highest-strength alloys known.

Time-elongation curves from the rupture tests on the two wrought alloys showed that the alloy with lower ductility, NR-82 (6059 modified-low carbon), had a lower deformation rate than did alloy NR-84 (N-155 modified-low carbon). This was true also for the lowest-ductility cast alloy NR-90 compared with NR-71 and NR-87. Attention is called to the fact that the specimen of alloy NR-71 (X-40) under 32,500 psi had excessively high elongation. The fracture of this specimen was of the single-crystal type, namely, an oval-shaped formation of the crystal adjacent to the fracture. This explains the high ductility.

Metallographic examination of the longest-time rupture-test specimens revealed a matrix filled with fine particles of excess constituent. This is the usual appearance of long-time rupture-test specimens of alloys of this type, the fine particles precipitating during the test and increasing the hardness of the material. This precipitation is considered to be an influential factor in the development of the outstanding properties of these materials.

A correlation, which shows the variation in rupture strength with temperature, obtained from the research program at 1500°, 1600°, and 2000° F (references 1, 2, and 4) with the NACA data at 1350°, 1700°, and 1800° F, is shown in figure 4 for the five alloys studied. Actually the only alloy for which rupture strengths are available over the complete temperature range is NR-71 (X-40). On the basis of the data available, the other two cast alloys with strengths of the same order of magnitude would be expected to vary in strength with temperature to about the same extent as NR-71. Alloy NR-71, incidentally, was the strongest of a group of cast alloys tested at 1700° and 1800° F. (See reference 4.) The two wrought alloys, NR-82 and NR-84, had practically identical rupture strengths at both 1350° and 1500° F. Higher-temperature data have not been determined on these two alloys.

CONCLUSIONS

From an investigation of the stress-rupture properties at 1350° F of two wrought alloys and three precision-cast alloys, the following conclusions were made:

The two wrought alloys, NR-82 (6059 modified-low carbon) and NR-84 (N-155 modified-low carbon), had identical 1350° F rupture strengths, although alloy NR-84 had much higher ductility. The strengths of these alloys are somewhat higher than those of standard N-155 alloy, but it is rather doubtful whether this benefit is sufficient to warrant the necessary increase in alloy content.

The three precision-cast alloys, NR-71 (X-40), NR-87 (Co-Cr-Ni base-9Mo), and NR-90 (Co-Cr-Ni base-5Mo, 5W) had 1350° F rupture strengths which compared favorably with those of alloy 422-19, the best cobalt-chromium-nickel base alloy previously investigated at 1350° F. They have much lower strengths, however, than the best chromium-base alloys. Although there was some difference in rupture strengths among the three cast alloys, there was not a consistent variation. Other factors, such as variations possibly due to varying crystal orientations between specimens, make it impossible to attribute strength differences observed to chemical composition.

University of Michigan
Ann Arbor, Mich., November 15, 1946

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1. Cross, Howard C., and Simmons, Ward F.: Progress Report on Heat-Resisting Metals for Gas Turbine Parts (N-102). NDRC OSRD Rep. No. 4717, Ser. No. M-477, Feb. 20, 1945.

2. Cross, Howard C., and Simmons, Ward F.: Final Report on Heat-Resisting Metals for Gas Turbine Parts (N-102). NDRC OSRD Rep. No. 6563, Ser. No. M-636, Jan. 21, 1946.

3. Freeman, J. W., Rote, F. B., and White, A. E.: High Temperature Characteristics of 17 Alloys at 1200° F and 1350° F. NACA ACR No. 4C22, 1944.

4. Freeman, J. W., Reynolds, E. E., and White, A. E.: The Rupture Test Characteristics of Six Precision-Cast and Three Wrought Alloys at 1700° and 1800° F. NACA ARR No. 5J16, 1945.

5. Freeman, J. W., Reynolds, E. E., and White, A. E.: An Investigation of the High-Temperature Properties of Chromium-Base Alloys at 1350° F. NACA TN No. 1314, 1947.

TABLE I

CHEMICAL COMPOSITION OF ALLOYS TESTED AT 1350° F

Alloy	Chemical composition (percent)										
	C	Mn	Si	Cr	Ni	Co	Mo	W	Cb	Fe	N_2
NR-82 (6059 modified-low carbon) J-631	0.17	1.20	0.69	25.29	32.0	30.85	3.35	2.23	1.03	——	0.03
NR-84 (N-155 modified-low carbon) J-632	.14	1.11	.57	23.08	23.82	24.38	4.25	1.26	1.10	——	.14
NR-71 (X-40)	.48	.64	.72	25.12	9.69	55.23	——	7.23	——	0.55	——
NR-87 (Co-Cr-Ni base-9Mo)	.52	.70	.69	22.54	19.17	Bal.	9.09	——	——	.9	——
NR-90 (Co-Cr-Ni base-5Mo, 5W)	.44	.76	.71	22.60	18.23	Bal.	5.09	5.18	——	.8	——

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TABLE II

RUPTURE-TEST DATA AT 1350° F FOR FIVE ALLOYS

Alloy	Stress (psi)	Rupture time (hr)	Elongation in 1 inch (percent)	Reduction of area (percent)
Wrought NR-82 (6059 modified-low carbon)	35,000	44.5	10	10.5
	30,000	229	9	10.9
	28,000	291.5	[a]8	12.5
	25,000	725	9	12
Wrought NR-84 (N-155 modified-low carbon)	33,000	106	26	26.5
	30,000	196.5	33	39.0
	27,000	338	[a]30	24.2
	25,000	718	[a]29	28.2
Cast NR-71 (X-40)	45,000	100	31	40.7
	40,000	232	18	37.7
	35,000	816	27	35.0
	32,500	1189	41	45.8
Cast NR-87 (Co-Cr-Ni base-9Mo)	45,000	84	20	27.0
	40,000	378	17	27.4
	37,000	775	22	31.8
	35,000	918	18	33.1
	34,000	1980	[a]13	35.0
Cast NR-90 (Co-Cr-Ni base-5Mo, 5W)	45,000	53	[a]23	20.7
	40,000	84	8.5	7.0
	37,500	542	12	13.3
	35,000	639	15	16.5
	34,000	960	8	10.2
	32,500	1630	7	6.4

[a]Fractured through gage mark.

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TABLE III

RUPTURE PROPERTIES OF CAST AND WROUGHT ALLOYS AT 1350° F AND

COMPARATIVE PROPERTIES OF OTHER ALLOYS

Alloy	Treatment	Stress for rupture in indicated time periods (psi)			Estimated elongation to rupture in indicated time periods (percent)		
		100 hr	500 hr	1000 hr	100 hr	500 hr	1000 hr
Wrought NR-82 (6059 modified-low carbon)	2200° F 1 hr W.Q. + 50 hr at 1350° F	32,500	26,000	24,000	10	9	9
Wrought NR-84 (N-155 modified-low carbon)	2200° F 1 hr W.Q. + 50 hr at 1350° F	32,500	26,000	24,000	25	30	30
Cast NR-71 (X-40)	50 hr at 1350° F	45,000	36,500	33,000	31	25	40
Cast NR-87 (Co-Cr-Ni base-9Mo)	50 hr at 1350° F	44,500	38,000	36,000	20	20	18
Cast NR-90 (Co-Cr-Ni base-5Mo, 5W)	50 hr at 1350° F	41,000	36,000	34,000	10	10	8
Wrought N-155[a]	Hot worked	28,000	22,000	20,000	10	6	6
Wrought low-carbon N-155[a]	Hammer forged from 2100° F to 1350° F	36,000	29,000	[b]27,500	17	12	---
Wrought low-carbon N-155[c]	2200° F 1 hr W.Q. + 50 hr at 1350° F	30,000	25,500	22,800	26	39	25
Cast 6059[a]	50 hr at 1500° F	36,500	32,500	[b]30,500	18	23	---
Cast 422-19[a]	50 hr at 1500° F	47,000	39,500	36,000	28	18	10
60Cr-25Fe-15Mo[d]	------------	68,000	56,500	52,000	4	5	5

[a]Data taken from reference 3.

[b]Obtained by extrapolation of stress-rupture curve.

[c]Data taken from unreported investigation on typical low-carbon N-155 bar stock in progress at the University of Michigan for the NACA.

[d]Data taken from reference 5.

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Alloy	Type chemical analysis								Heat treatment
	C	Cr	Ni	Co	Mo	W	Cb	N2	
□ Wrought NR-82	0.17	25	32	31	3.4	2.2	1.0	0.02	2200°F 1 hr W.Q.+50 hr at 1350°
△ Wrought NR-84	.14	23	24	24	4.2	1.3	1.1	.14	2200°F 1 hr W.Q.+50 hr at 1350°
○ Cast NR-71 (X-40)	.48	25	10	55	-	7.2	-	-	50 hr at 1350°F
× Cast NR-87	.52	23	19	Bal.	9	-	-	-	50 hr at 1350°F
● Cast NR-90	.44	23	18	Bal.	5	5.2	-	-	50 hr at 1350°F

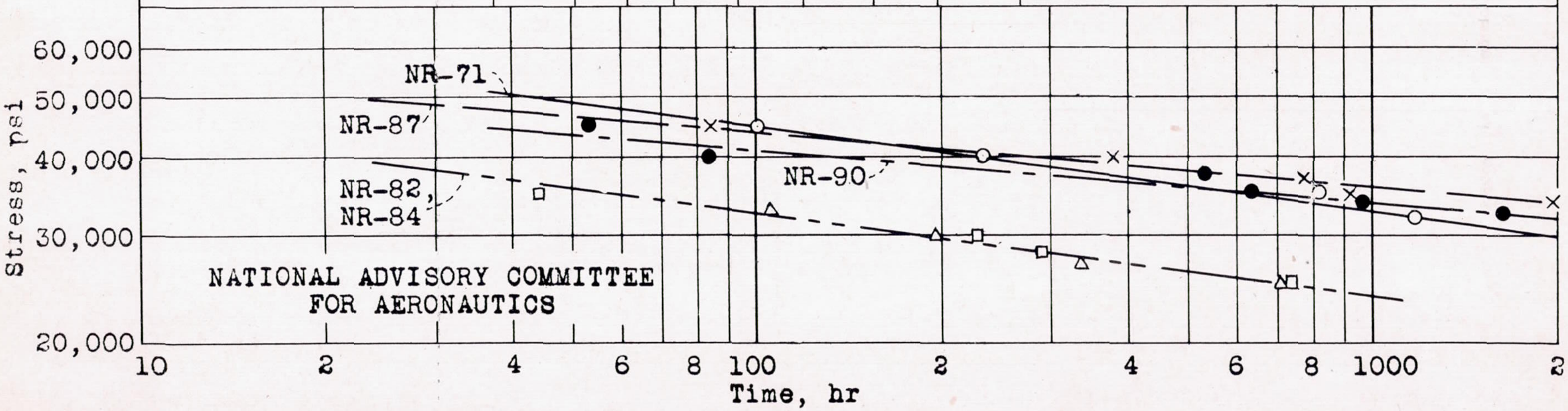
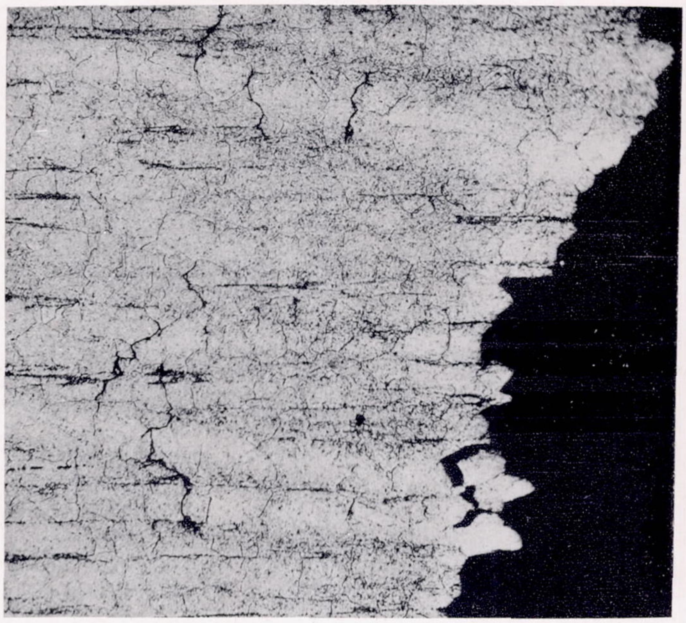
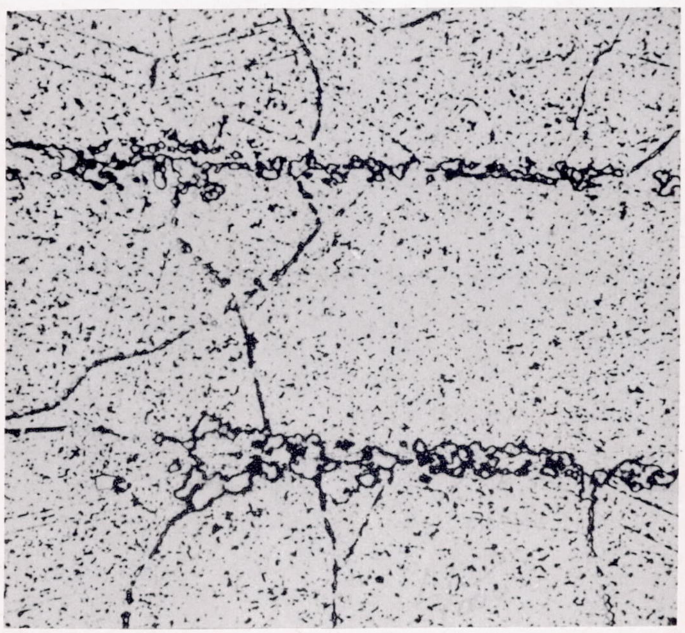


Figure 1.- Curves of stress against rupture time at 1350° F for wrought alloys NR-82 and NR-84 and cast alloys NR-71, NR-87, and NR-90.



Fracture, 100X



Interior, 1000X

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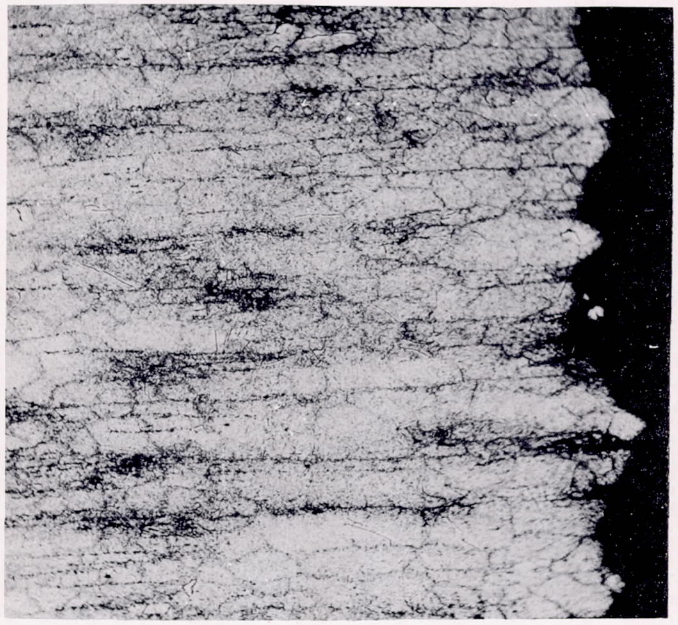
(a) Alloy NR-82. 725 hours for rupture under 25,000 psi; Vickers hardness 294.

Figure 2a,b.- Microstructures of specimens of wrought alloys NR-82 (6059 modified-low carbon) and NR-84 (N-155 modified-low carbon) after completion of 1350° F rupture test. Electrolytic chromic acid etch.



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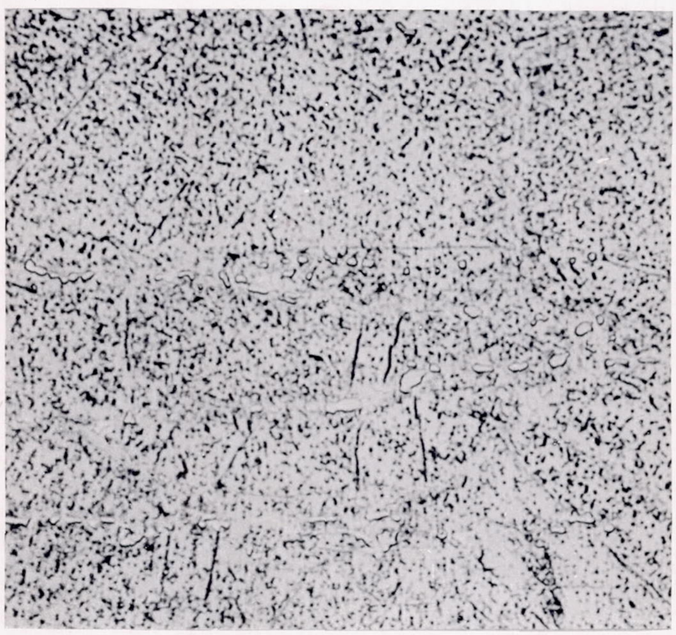
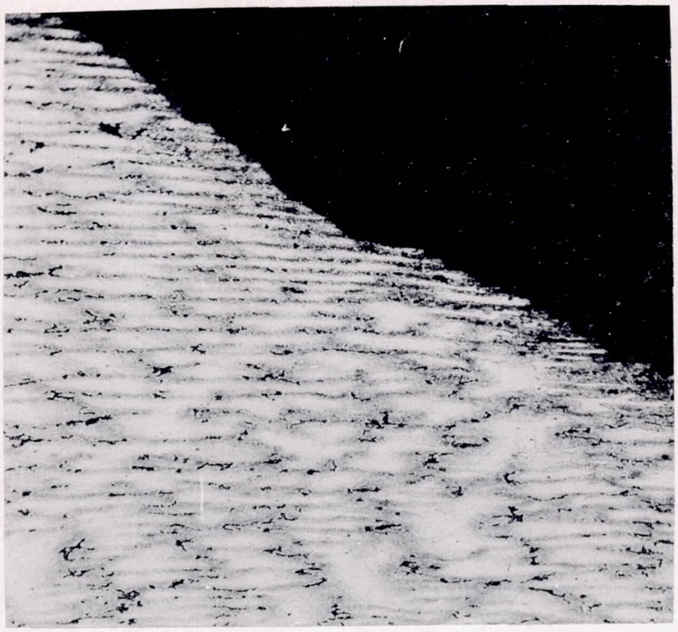


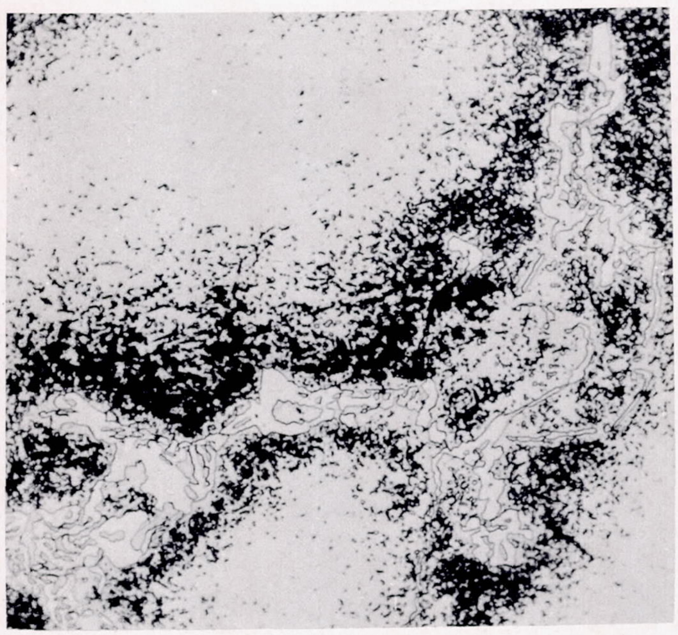
Interior, 1000X

(b) Alloy NR-84. 718 hours for rupture under 25,000 psi;
Vickers hardness 284.

Figure 2.- Concluded.



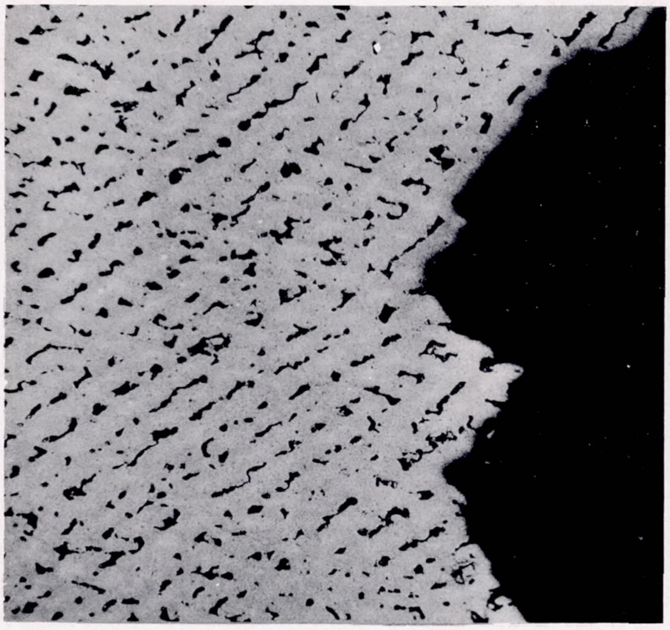
Fracture, 100X



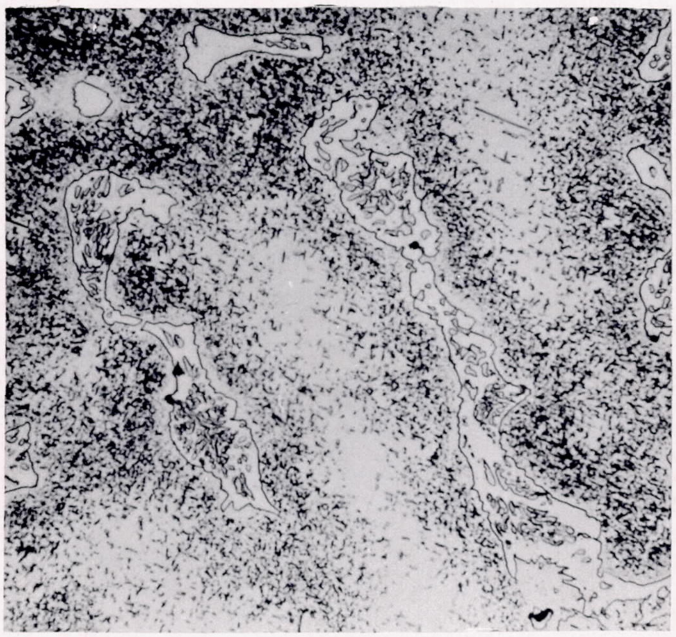
Interior, 1000X

(a) Alloy NR-71. 1189 hours for rupture under 32,500 psi; Vickers hardness 466.

Figure 3 (a to c).- Microstructures of specimens of precision-cast alloys NR-71 (X-40), NR-87 (Co-Cr-Ni base - 9Mo), and NR-90 (Co-Cr-Ni base - 5Mo, 5W) after completion of 1350° F rupture test. Electrolytic chromic acid etch.



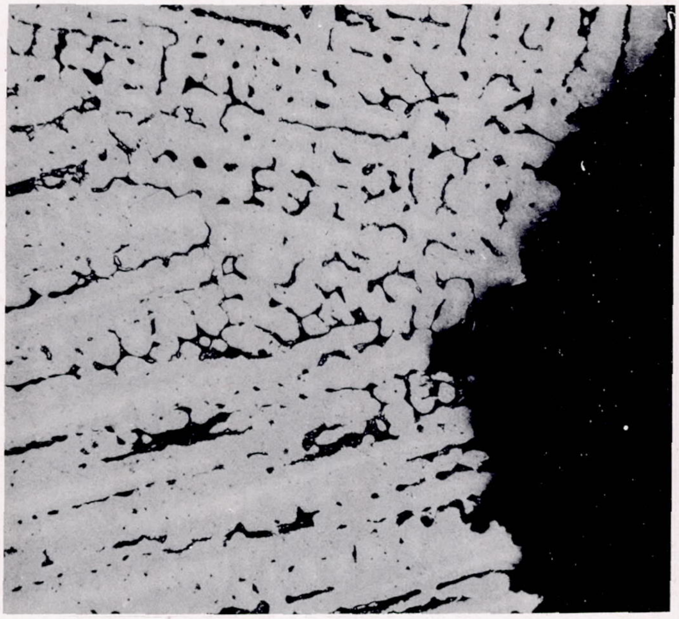
Fracture, 100X



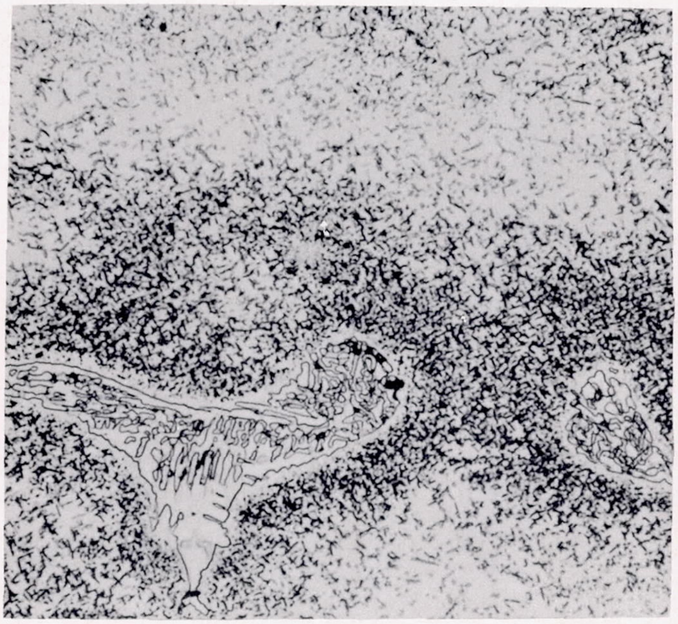
Interior, 1000X

(b) Alloy NR-87. 1980 hours for rupture under 34,000 psi; Vickers hardness 412.

Figure 3.- Continued.



Fracture, 100X



Interior, 1000X

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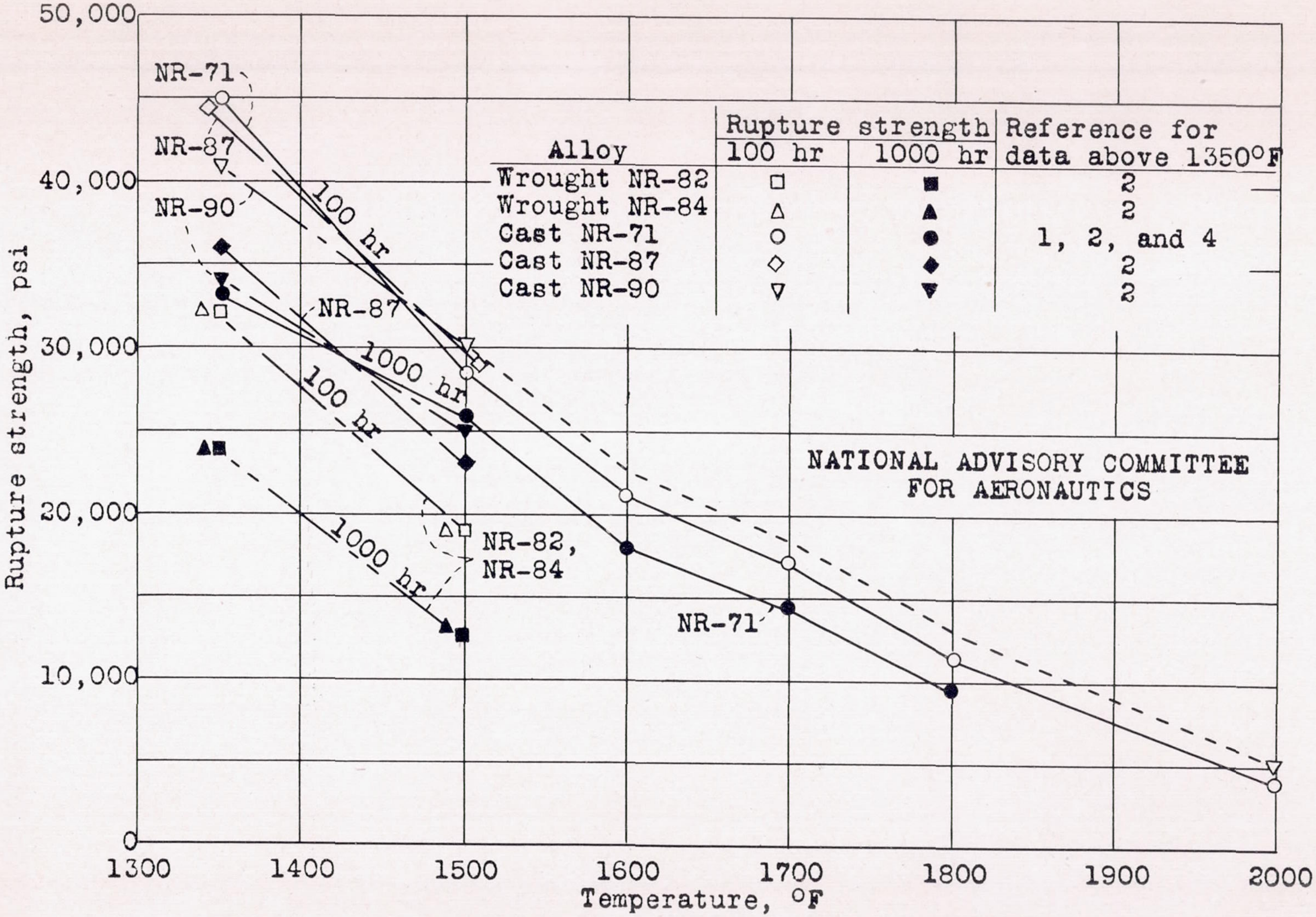
(c) Alloy NR-90. 1630 hours for rupture under 32,500 psi; Vickers hardness 405.

Figure 3.- Concluded.



Alloy	Rupture strength 100 hr	Rupture strength 1000 hr	Reference for data above 1350°F
Wrought NR-82	□	■	2
Wrought NR-84	△	▲	2
Cast NR-71	○	●	1, 2, and 4
Cast NR-87	◇	◆	2
Cast NR-90	▽	▼	2

Figure 4.- Variation of rupture strengths with temperature for wrought alloys NR-82 and NR-84 and cast alloys NR-71, NR-87 and NR-90.